Technical Note 1970-31

Fabrication of Flexible Loop Antenna

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5 October 1970

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Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts

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LINCOLN LABORATORY

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ABSTRACT

Three flexible loop antennas were fabricated for evaluation and testing as underwater, towed, ELF receiving antennas. This report presents a detailed description of the fabrication process and the materials used in the fabrication.

Accepted for the Air Force
Joseph R. Waterman, Lt. Col., USAF
Chief, Lincoln Laboratory Project Office

A. Introduction

The antenna is a long, thin solenoid with bundles of magnetic wire as a core (Fig. 1). A plastic bifurcated tube houses the bundles of magnetic wires and the tube is filled with Freon to mechanically isolate the bundles from external strain. The bundles are 23 inches long and are staggered in the tube to form a roughly laminated core. A single layer coil of aluminum wire is wound over the tube, and the return wire for the coil lies beneath the coil. A twisted wire cable is connected to the antenna as a transmission line and a length of cable is also attached to the other end of the antenna for a tail. The antenna, transmission line and tail are jacketed together in a buoyant sheath with fiberglass strength members. Provisions have been made for the installation of electrodes either side of the loop antenna to give a combined electrode-pair and loop antenna.

Three 10 ft. long antenna with several hundred feet of transmission line between them were first fabricated to evaluate the fabrication procedure and mechanical design. After successful completion of mechanical tests of the evaluation antennas, three antennas were then fabricated for sea test measurements. The antennas are 50, 100 and 150 ft. long and each has a 1500 ft. length of transmission line as a tow line and a 300 ft. tail.

Fabrication of the antennas was done principally at Lincoln Laboratory. Bundling the magnetic wires and loading them into the bifurcated tube was the most difficult and time consuming step in the fabrication. Since commercial coil winding companies did not have suitable equipment to wind the antenna coil and tape the assembly, a coil winder and tape winding machine were designed and built at the laboratory to meet the requirements. In the critical areas of sealing the Freon in the bifurcated tube and joining the antenna to the transmission line, special procedures were developed to ensure high reliability. In order to make a watertight seal at the tail end of the antenna, an injection molding technique was developed at the laboratory to effectively seal the foam polyethylene cable jacket. The sheathing of the antenna assembly

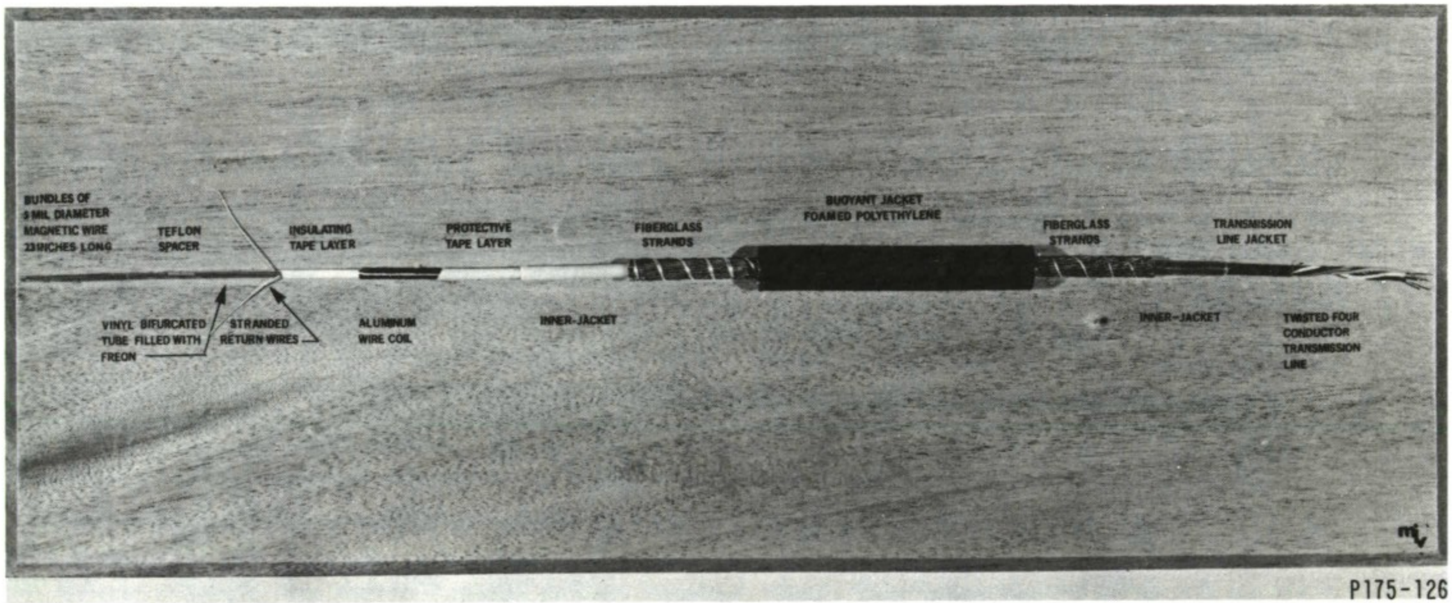


Fig. 1. Cutaway model of flexible loop antenna.

with the buoyant jacket and strength members, one of the last steps in the fabrication, was performed by a commercial cable company and was the only major step in the fabrication not performed in-house.

B. Fabrication

1. Bifurcated Plastic Tube

a. Bifurcated tube - The bifurcated tube provides a housing for the magnetic wire bundles and serves as the longitudinal strength member for the antenna assembly. The PVC (polyvinylchloride) plastic tube is extruded using clear, rigid vinyl of high durometer, and the tube has a squat figure 8 cross-section.

b. Sizing - The cross-sectional variations of the major and minor axis for the vinyl tube were measured in the test jig shown in Fig. 2. The vinyl tube is pulled slowly through the jig as the diameter variations are indicated by the micrometer dials. The guides 1, 2, 3, 4 prevent twisting of the oval tube during measurements.

The measured cross-sectional dimensions "a" (Fig. 3) varied considerably over short lengths, and the tubing was sized for a tolerance of ±5 mils about the average dimension. Dimension "b" did not vary as much as "a"; the tolerance for "b" was ±2 mils. The web and outside wall thickness measured between 7 - 10 mils.

Ultimate tensile strength of the tube is 22 pounds.

2. Leak Testing Bifurcated Tubing - The following procedure was used to check the bifurcated tube for holes which would cause a Freon leak:

a. Seal both chambers at one end of the tubing using the method in step 8.

b. Using a mold made to fit the cross-section of the bifurcated tube, a cylindrical block of G. E.'s Silicone RTV-511 (1" long, 1/4" OD) is molded to the open end of the tube.

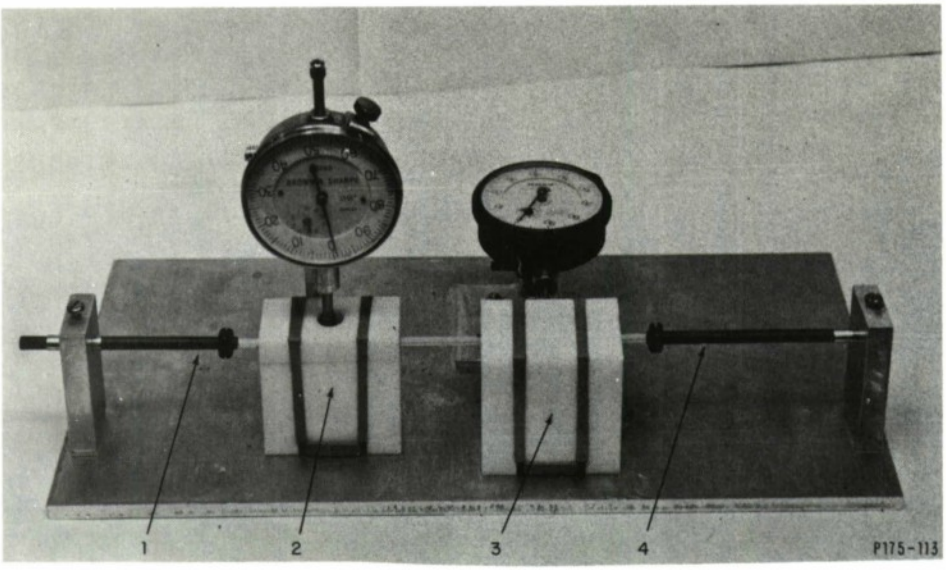


Fig. 2. Test jig used to measure cross-sectional dimensions of bifurcated tubing.

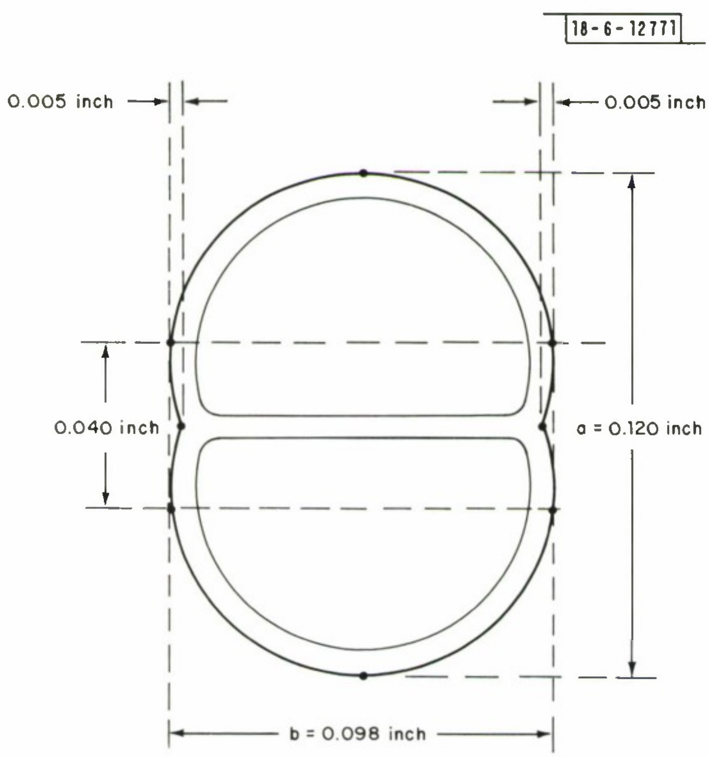


Fig. 3. Measured cross-sectional dimensions (average) of bifurcated tubing.

c. A rubber hose is fitted over the RTV-511 block and clamped to the block.

d. The rubber hose is connected to a high vacuum system and the tube is evacuated until the pressure stabilizes.

e. The vacuum pump is then shut off, and the increase in pressure is measured as a function of time. Table 1 is representative of acceptable leak rates.

3. Bundling of Magnetic Wire

a. Magnetic Wire

The magnetic wire is 4-79 molybdenum permalloy, 0.005 inches in diameter. The relative permeability of the wires varies between 20,000 and 35,000. The wire is delivered on the mandrel used in annealing the material, and the wires after being cut from the mandrel are about 26 inches long.

Because an oxide coating on the first mandrel delivered made it very difficult to separate and remove the wires, the complete mandrel was dipped into a tank containing a 30% solution of hydrochloric acid for 15 minutes, then rinsed in a neutralizer. The second delivery was made with the wires grouped in bundles of 40 wires and was annealed on 4 mandrels. With this delivery, there was no oxide coating. Five pounds of wire were ordered in each case.

b. Bundling

The magnetic wire bundles are approximately 23 inches long containing 1 to 30 wires each of five mil diameter. The bundles containing less than 10 magnetic wires had their diameter increased by adding stainless steel wires of 10 mil diameter. The number of stainless steel wires added were 3 for bundles of 1 to 3 magnetic wires, 2 for bundles of 4 to 6 magnetic wires and 1 for bundles of 7 to 9 magnetic wires.

The individual wires are held in a bundle by cementing one end with

TABLE 1

Pressure Tests of Bifurcated Tubing

Test	Pressure, Torr		
	Initial	30 sec.	1 min.
System	2.0×10^{-6}	3.5×10^{-5}	5.4×10^{-5}
Tube No. 1	5.5×10^{-6}	-----	4.7×10^{-4}
Tube No. 2	9.5×10^{-6}	2.4×10^{-4}	8.4×10^{-4}
Tube No. 3	6.0×10^{-6}	2.5×10^{-4}	4.9×10^{-4}
Tube No. 4	7.0×10^{-6}	5.0×10^{-4}	9.8×10^{-4}

a drop of moisture cure polyurethane resin (Fig. 4) and binding the other end with a coil formed by one of the magnetic wires (Fig. 5). The purpose of the coil is to permit the individual wires to slide in the bundle as they adjust to the different arc lengths when the antenna is flexed.

The wire bundles, after assembly, are temporarily stored in 2-1/2 foot lengths of straightened bifurcated tube.

4. Grading Bundles

a. Permeability Measurement - An HP X-Y recorder, model 2FA was fitted with a 2 ft. coil along the X-axis of the recorder, and mounted about 8 inches away from the recorder case with non-magnetic material (Fig. 6). The turns per unit length for the coil is 2.0×10^3 turns/meter, and the ID of the coil is large enough to slip a bifurcated tube into the coil. A narrow search coil of 100 turns slides on the 2 ft. long coil and is connected and driven by the arm which moves along the x-axis.

The circuit diagram for the measurement is shown in Fig. 7. The wave analyzer BFO output is set for 1 vrms at 500 Hz and is monitored during the measurements by the frequency meter and RMS voltmeter. The wave analyzer is set for a sensitivity of 3 mv full scale, 10 Hz bandwidth and a meter time constant of $< .1$ sec. The x-y recorder is set for a 1 sec/inch sweep.

The calibration of the set-up for a bundle of 30 wires gives a relative permeability of $1000/60\mu v$ of signal at the input to the wave analyzer.

1) Calibration. Connect the BFO directly into the input of the wave analyzer, and set the level for a 3.0 full scale reading. Adjust y-axis gain for full scale deflection. Adjust meter zero on the wave analyzer, and check y-axis zero on the recorder. Set up is now calibrated for a full scale recorder reading of 50,000 relative permeability for 30 wires.

2) Align 2 ft. coil normal to geomagnetic field. Recorder should be on non-magnetic stand and away from metal objects.

3) Position bundle of magnetic wire in the middle of the

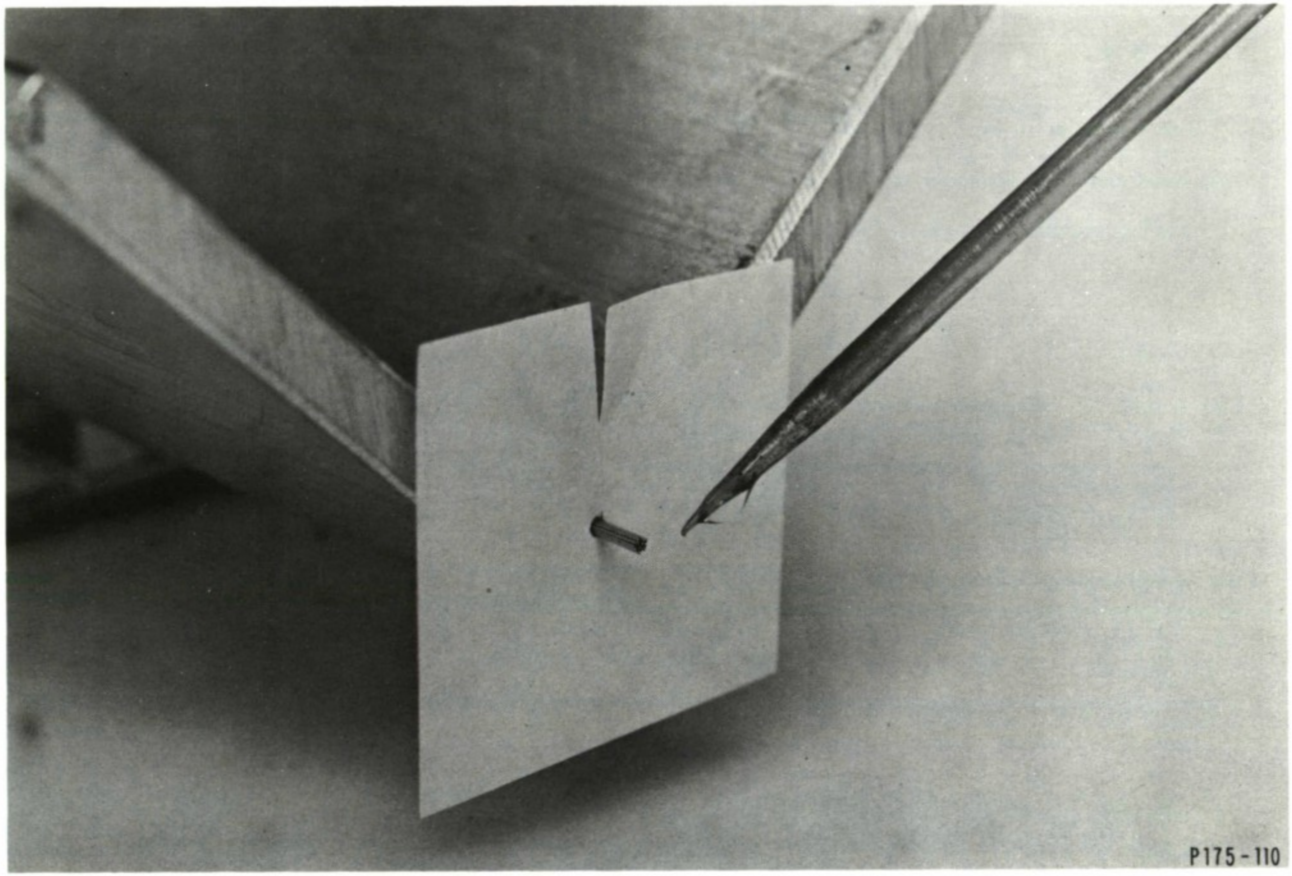


Fig. 4. Cemented end of magnetic wire bundle.

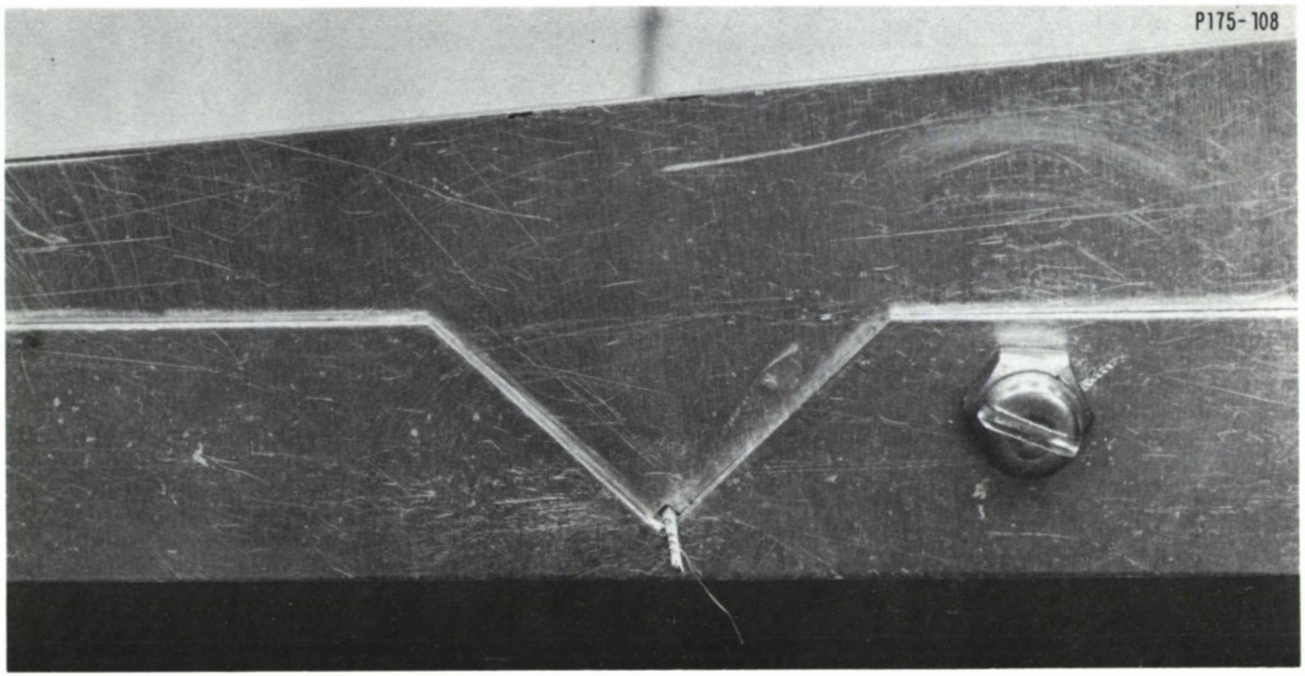


Fig. 5. Coil end of magnetic wire bundle.

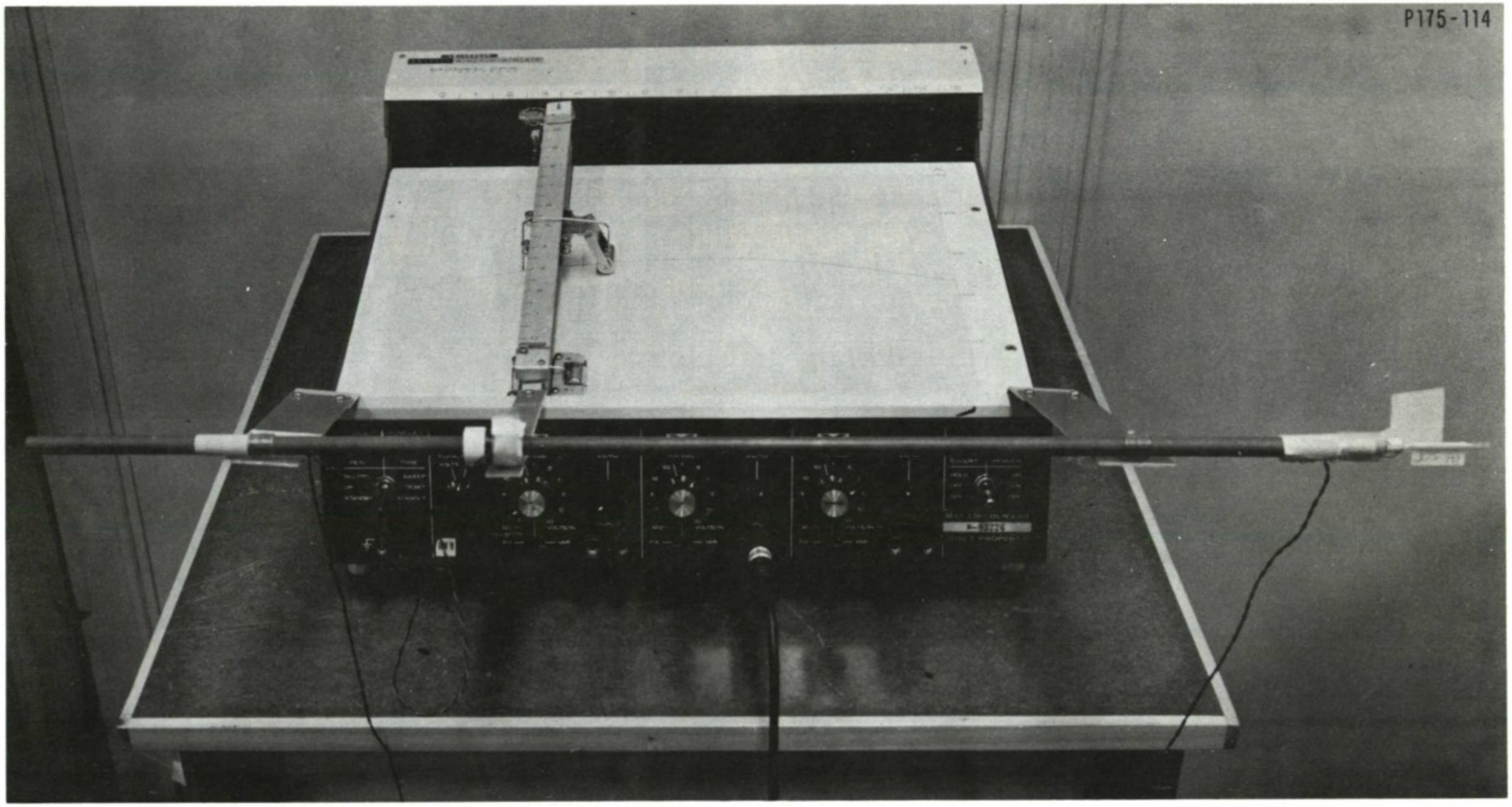


Fig. 6. Plotter with search coil.

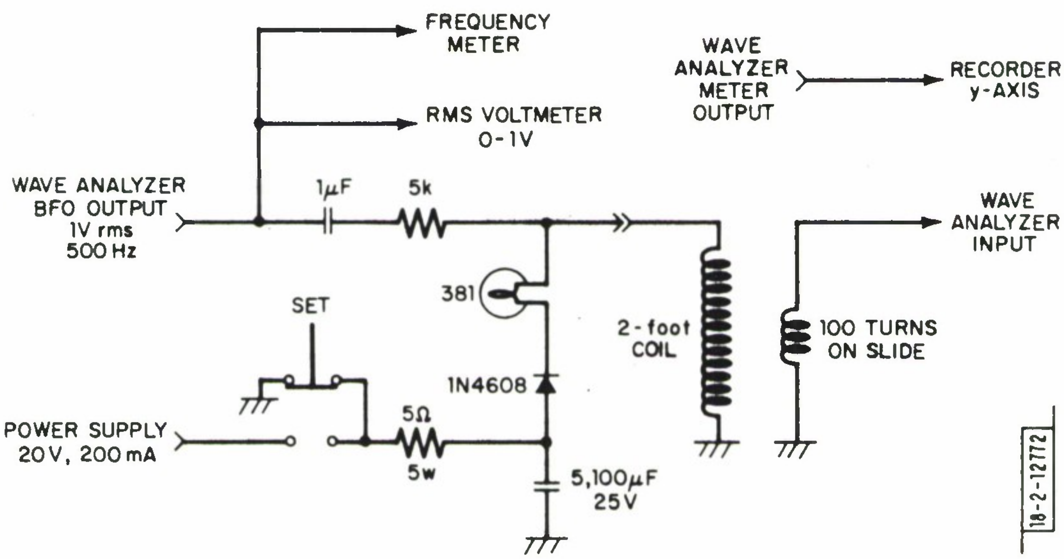


Fig. 7. Schematic of surge current circuit and instrumentation connections.

x-axis sweep.

4) Activate current surging circuit to initialize the magnetic conditions.

5) Sweep recorder to plot the permeability.

6) Classify the bundle of magnetic wire as being uniform (permeability peak occurring ± 1 inch from center of bundle) or non-uniform (peak outside ± 1 inch of center). Reject the non-uniform bundles.

7) Mark maximum permeability on the bundle.

b. Permeability Distribution

In measuring the permeability of the bundles of magnetic wire, each bundle was treated as if it consisted of 30 wires each in order to make comparisons between bundles. The measured values (permeability indices) were then tabulated and a distribution was selected to provide the best fit to a parabolic distribution with the available bundles. The distribution is plotted for each of the antennas in Fig. 8. The bundle number corresponds to the numbering system shown in Fig. 10.

5. Loading Bundles into Bifurcated Tube

The magnetic wire bundles are loaded into the bifurcated tube using a technique of pulling the bundles in the chambers of the tube with a thread/or magnet. This loading process is done with the tube positioned horizontally and taut over supporting stands.

The thread is initially inserted into the tube by attaching it to a steel rod and pulling the rod through with a magnet. This cotton thread is later used to pull the nylon threads into the tube.

The nylon thread comes in spools of 4800 yards with tensile strength exceeding 80 oz. It is not guaranteed to be free of knots and necessitates that two threads be used. When the wire bundles are loaded into the tube the thread is spooled at the far end of tube and saved. When the first knot is

encountered, the thread is cut and removed from the tube. When the next knot is encountered the thread is backed up and re-spooled on the supply spool. This process is repeated until that chamber of the bifurcated tube is loaded.

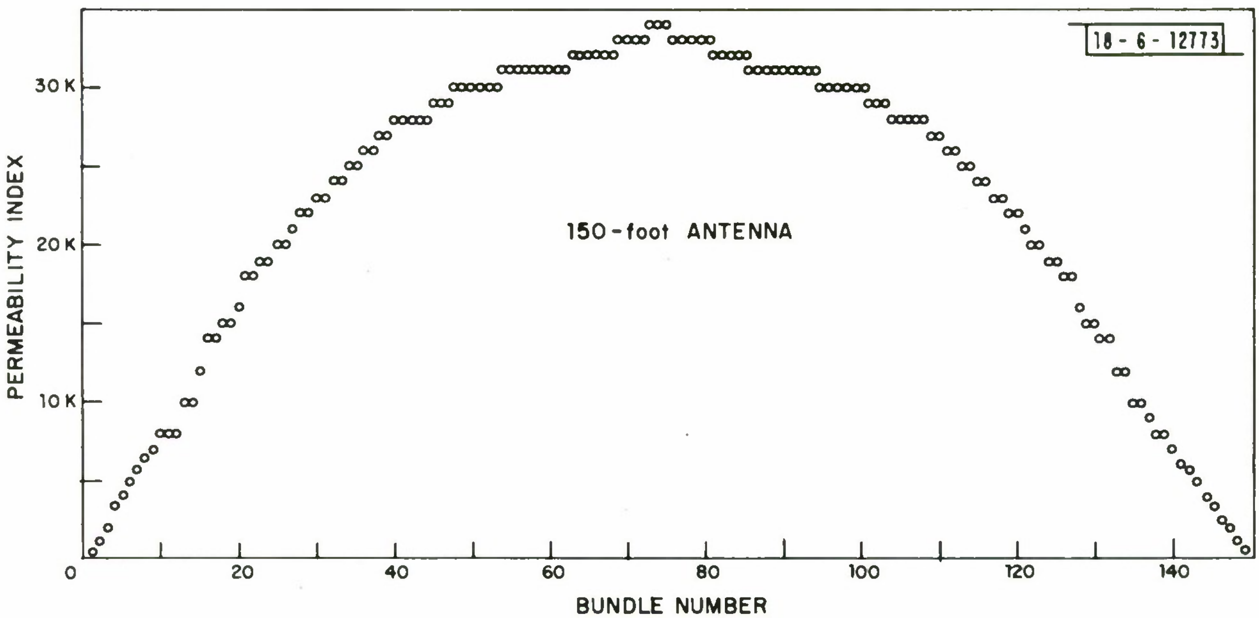
The nylon thread develops an electrostatic charge as it is pulled through the tube. To drain this charge, the thread is pulled over a pad moistened with antistatic solution before entering the tube.

Teflon spacers are threaded on the nylon threads before they are pulled into the tube. The spacers are held apart with masking tape to prevent binding of the thread (Fig. 9). If knots occur in the thread these spacers become removed from the tape thus detecting knots. To insure this protection for the complete loading process additional spacers are always added.

The magnetic wire bundles are graded for permeability and numbered sequentially for loading. The low permeability bundles containing twenty wires or less are pulled into the tube last with a magnet. The staggered loading of the tube is shown in Fig. 10.

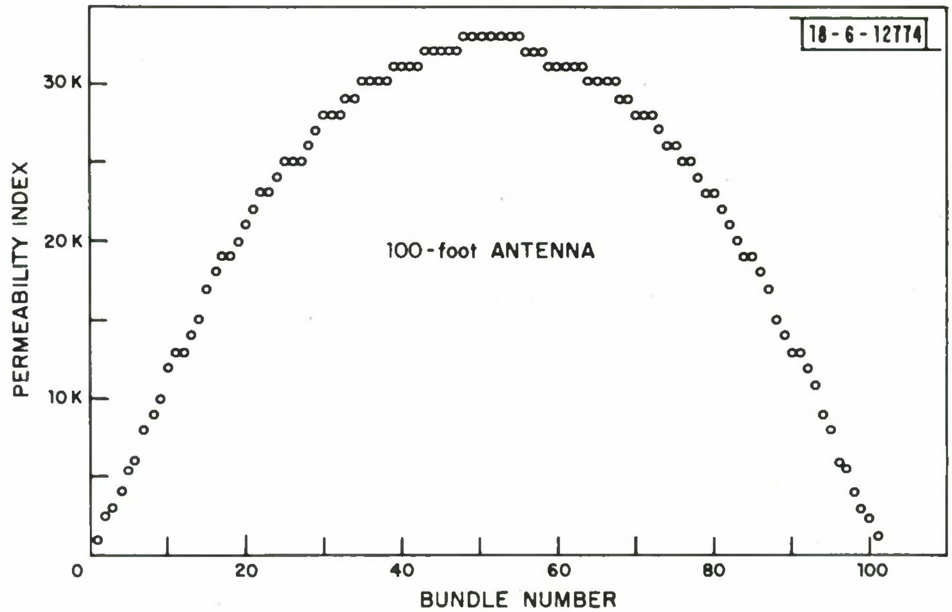
The wire bundle is attached to the thread with a half hitch knot, (Fig. 11) and pulled into the tube with approximately 16 oz. of tension using a spring scale. The thread is prevented from slipping from the wire bundle by keeping a minimum of 8 oz. of tension at the supply spool. Preceeding each bundle pulled into the tube is a 3/4" long Teflon tube spacer. These spacers are locked between crimps made with the tool shown in Fig. 12. The spacers are placed on 24" centers along the tube.

Prior to loading a bundle, crimp No. 1 (Fig. 11) is made. The bundle is released from the thread after the spacer is locked with crimp No. 2. To release the bundle the tension is removed at the supply spool and the thread is pulled at the far end of the tube. The thread should slide off with less than 20 oz. of pull. If the thread gets pinched between the bundle and the crimp, pulling the bundle back an inch and attempting again will, most often, be sufficient to release the bundle. In difficult cases the wire bundles can be

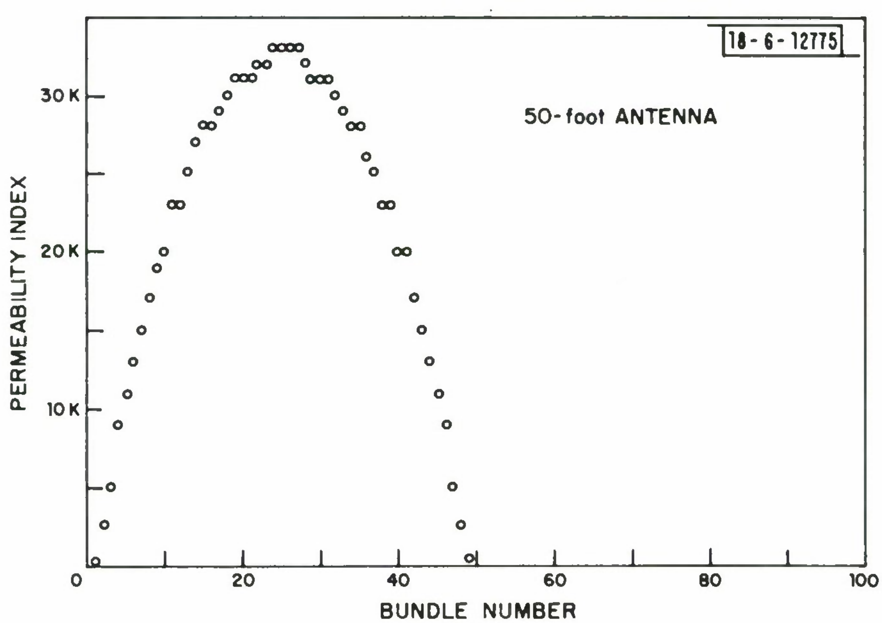


(a)

Fig. 8. Magnetic core grading for 150, 100, and 50 foot antennas.



(b)



(c)

Fig. 8. Continued.

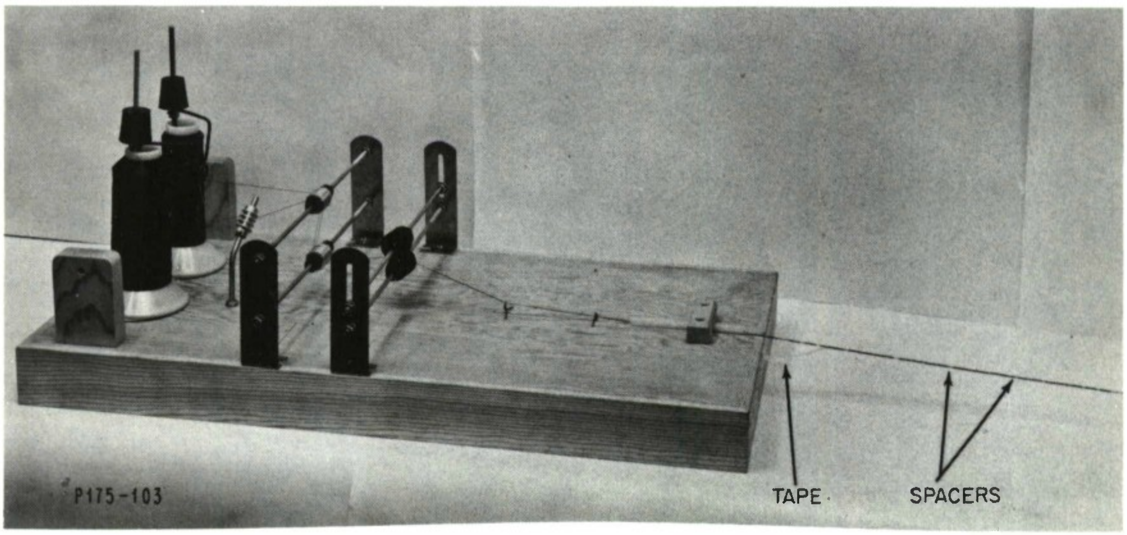


Fig. 9. Nylon thread feeder with Teflon spacers.

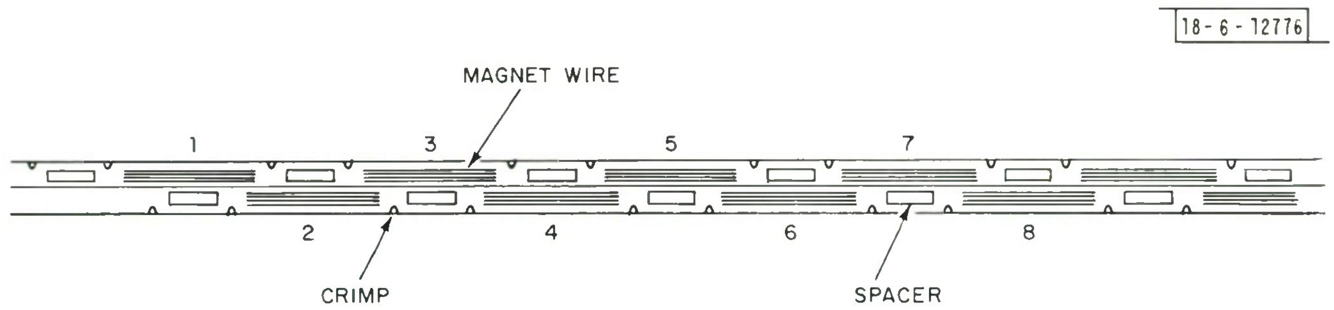


Fig. 10. Positioning of magnetic wire bundles and spacers.

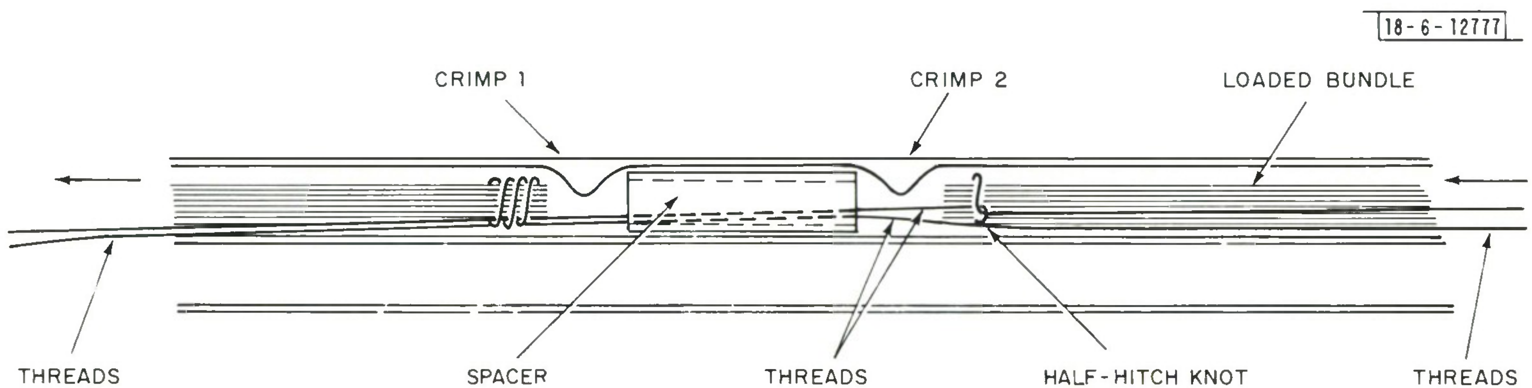


Fig. 11. Loading of magnetic wire bundle into bifurcated tube.

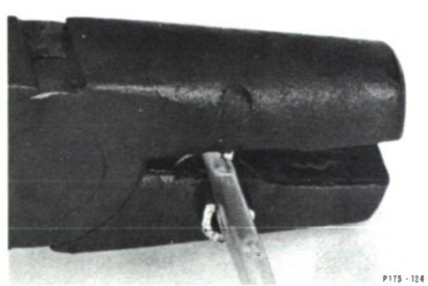


Fig. 12. Crimping tool.

pulled back with a magnet out of the half hitch knot when all the tension is released from the thread. Difficulty in releasing the bundle from the thread can be minimized by rigid inspection of the cemented end of the wire bundle for uniform cross-section of the bundle, bent/hooked wires and lumps of polyurethane resin.

A jamming problem and a break in the thread on the 100 ft. antenna made it necessary to cut into the bifurcated tube, and as a result three bundles are missing on both ends of the 100 ft. antenna. After successfully completing the loading of the 150 ft. antenna, the end of the thread twice snagged on the coil end of two bundles as it was being removed from the bifurcated tube. This required that the tube be cut into in order to release the thread. Both cut sections, though, were patched using a technique similar to that in step 8. A small teflon tube was placed below the patch to maintain a passage necessary for the Freon filling step.

6. Filling Crimps

a. The loaded bifurcated tube is wrapped around a 2 ft. diameter tube so that the web is normal to the surface. A small drop of epoxy (Material List, item 18) is placed in each crimp and left to dry 24 hours. The cylinder is then inverted and the filling repeated.

b. After the epoxy has completely hardened, a sizing die is drawn over the tubing to remove any excess epoxy, and to assure that the tubing will not bind in the taping machine.

7. Freon Injection

The following procedure is used to inject the E3 Freon into both chambers of the bifurcated tube with a minimum amount of trapped air in the tubing:

a. Connect adaptor fitting and off-on valve to one end of bifurcated tube with shrink tubing and Eccoprime B-25 sealing compound. Connect adaptor and valve to vacuum pump through trap and needle valve. Place other end of bifurcated tube in bottle of Freon.

b. Slowly open needle valve and begin filling bifurcated tube.

c. Close needle valve when desired filling rate occurs and let filling continue on vacuum in trap.

d. When Freon in bottle is near depletion, close valve at end of tube to hold Freon in the tube, and empty Freon in trap back into the bottle.

e. Continue circulating Freon through bifurcated tubing until air bubbles are scrubbed from the wire bundles and spacers.

f. Close valve at end of tube, wait for bubbles of Freon to collapse, then open valve at end of tube to atmospheric pressure.

g. Close valve at end of tube, and take other end out of bottle of Freon.

h. Quick seal the bifurcated tube at each end by heating the tube with a heat gun, and pinching off the tube with pliers.

8. Sealing Bifurcated Tube

The bifurcated tube is first cut at one end 24 inches from the final crimp. This length is required for sealing and joining and also to provide the lead-in and tail lengths necessary for the subsequent winding operations.

The Freon is removed until the Freon level in both chambers is 3.5 inches from the crimp and a half-inch blocking piece is pushed into each chamber, leaving 0.5 inches of air space above the Freon level. The blocking piece can be of any inert material and should be a push fit in its chamber.

Into the 5/8 inch long section of tube immediately above the blocking piece is injected the plasticized PVC mixture of sealing material, using a hyperdermic syringe with a No. 19 needle, 7/8 inch long which pierces the tube 5/8 inch from the upper end of the blocking piece. The needle first pieces obliquely both the outer wall and the web to inject sealant into the chamber remote from the pierced outer wall. Then, using the same hole in

the outer wall, the nearer chamber is injected with sealant. This procedure preserves sufficiently the mechanical strength of the tube.

The sealant material is cured by wrapping the tube with adhesive aluminum tape over a length 6 inches long centered on the sealant-filled section, clamping a 1 inch long split brass block (grooved to accept the wrapped tube) onto the center of the wrapped section and maintaining the block at 270°F for one minute. Heat is applied, as needed, to the block with a soldering iron. An electronic thermometer with a remote thermometer attached to the block monitors the block temperature.

When cool, the tape is removed and the seal inspected. If it appears to be unsatisfactory, the sealing operation can be repeated with the Freon level now 0.5 inch from the final crimp. In this event, however, the tail or lead-in required for the winding operations will have to be provided after sealing, since it must be cut off to repeat the seal.

The seal at the other end of the tube is made in the same manner.

9. Tri-Tape Winding and Return Wires

The return wire for the coil and an extra return wire (for the electrode-pair antenna) lie in the "V" grooves which run parallel along bifurcated tube. They are held in place by 3 layers of 1/4" wide, 1 mil thick polyester tape. The tape provides the insulation between the return wires, No. 26 stranded copper wire, and the coil which is wound on the tube.

The placement of the wires and the wrapping of the tape is done by the machine shown in Fig. 13. The wires are placed in the grooves of the bifurcated tube by pulling the tube through a hole having a diameter slightly larger than the major axis of the oval tube. The return wires are captive in the space adjacent to the grooves (Fig. 14). The wires once positioned are immediately wrapped with three layers of tape (Fig. 15). Each tape is wound non-overlapping and staggered to insure continuous insulation between return wire and coil. The machine wraps at the rate of 20 feet per hour.

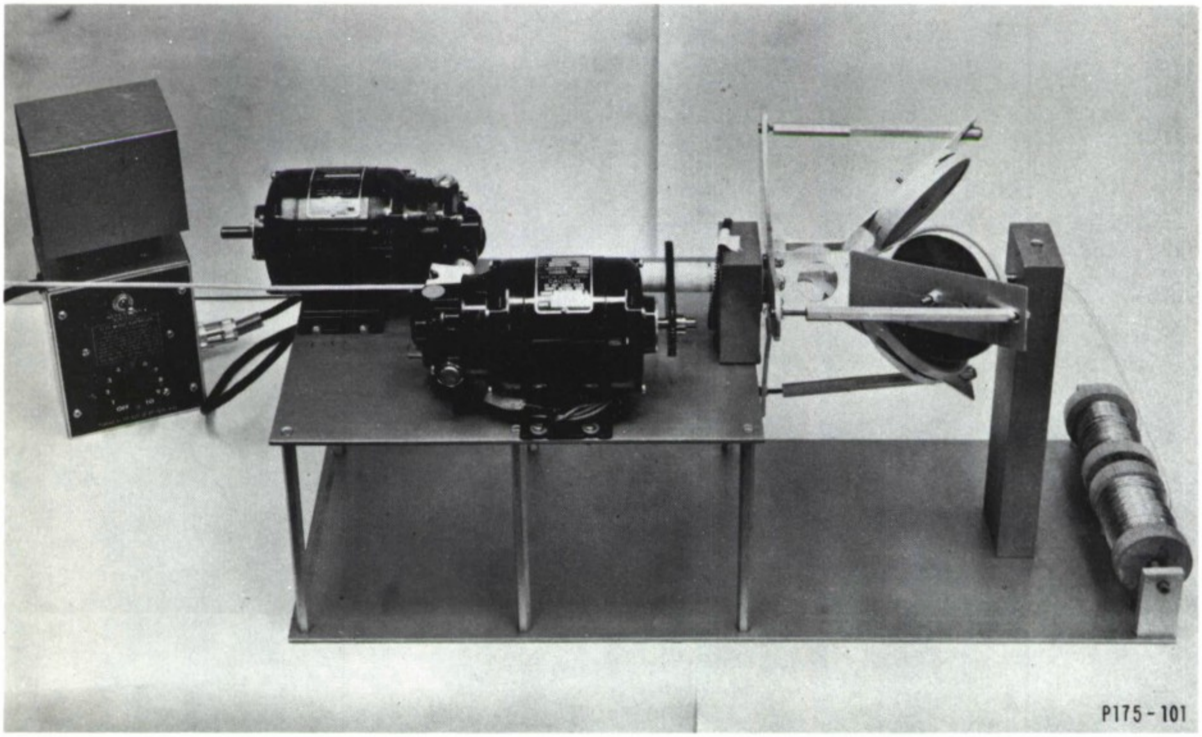


Fig. 13. Tri-layer wrapping machine.

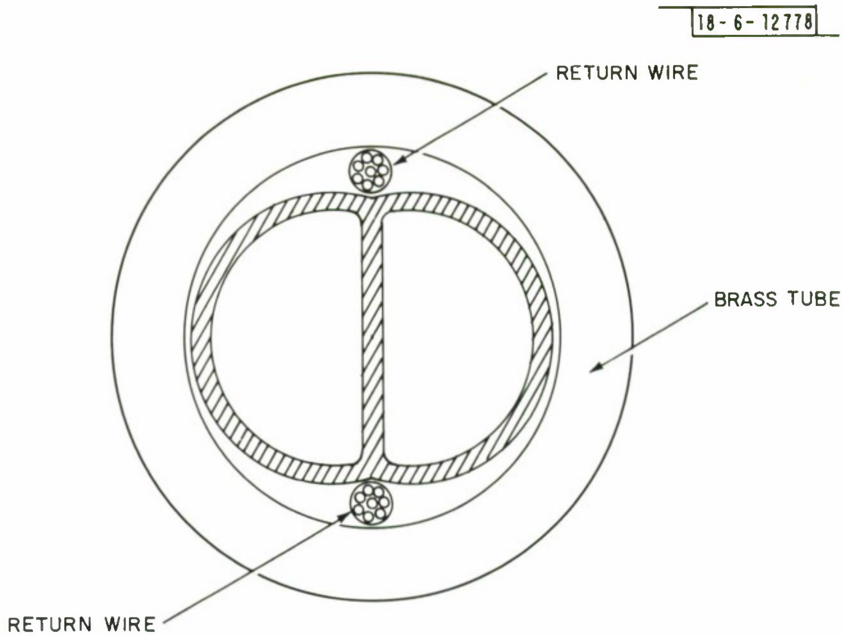


Fig. 14. Placement of return wires.

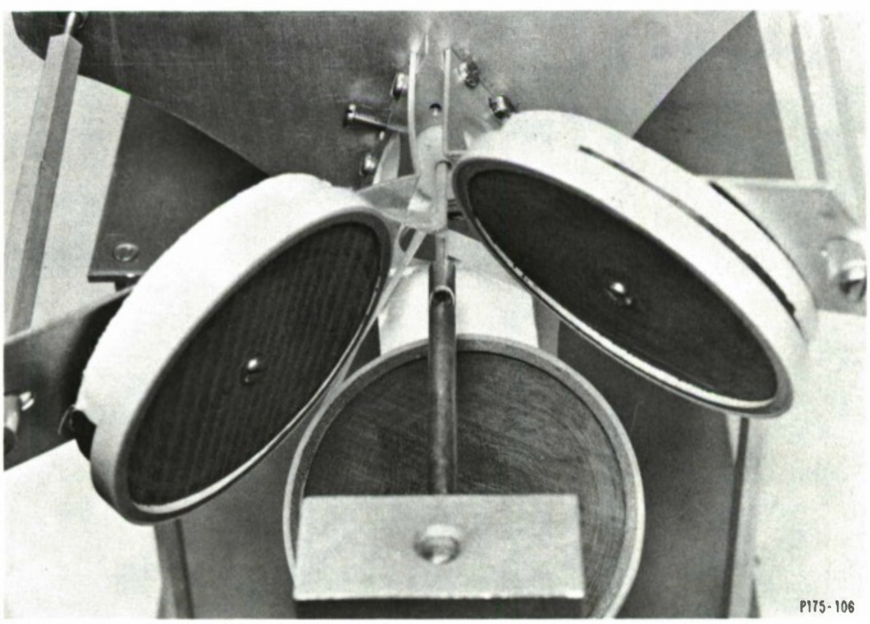


Fig. 15. Taping of return wires to bifurcated tube.

10. Coil Winding

The antenna coil is wound of No. 26 aluminum wire with a turn ratio of 45 turns/inch. It is wound at the rate of 15 feet/hour by the coil winder shown in Fig. 16 and 17. The antenna is drawn into the machine by a rubber friction drive (A) which gently compresses on the sides of the taped bifurcated tube as it moves the antenna through the winding assembly. The turns/inch ratio is adjusted by selecting PIC gears B and C.

11. Taping Coil

A protective layer of 1 mil polyester tape is wound over the coil to lock the coil turns in position and for added protection against abrasion of the wire insulation. This is wrapped with the tape wrapping machine at the rate of 50 feet/hour (Fig. 13, 18). In this mode the PIC gear, FP12-48, is replaced with gear FP-1272.

12. Sizing and Inspection of Twisted Four-Conductor

The twisted four conductor wire was sized by pulling the wire through a ring having an inside diameter of 173 mils. Actual diameter measurements were made with a micrometer at 50 foot intervals. The surface of the jacketed wires was examined for defects during the sizing operation.

13. Antenna and Four-Conductor Cable Connection

The twisted four-conductor cable is used for the transmission line and tail sections. The outside diameter of the cable is the same as the OD of the aluminum wire coil. Two wires are used for the electrical connection to the loop antenna. The other two are available for electrical connections to an electrode-pair antenna (Fig. 19).

a. Mechanical and Electrical

The forward and aft ends of the antenna are joined to the lengths of twisted four-conductor cable forming the transmission line and tail in the manner shown in the scale diagram shown in Fig. 20. Two views

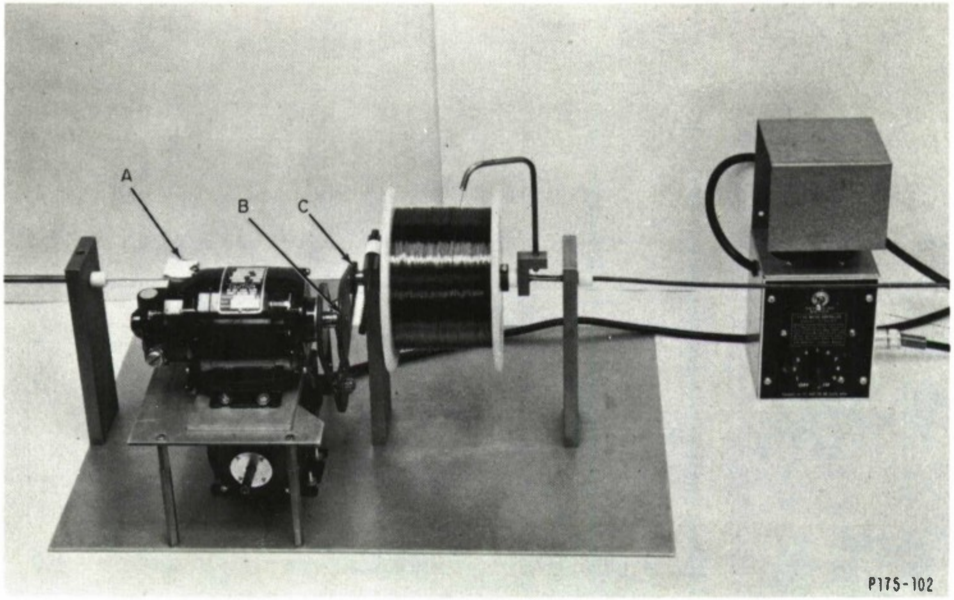


Fig. 16. Coil winding machine.

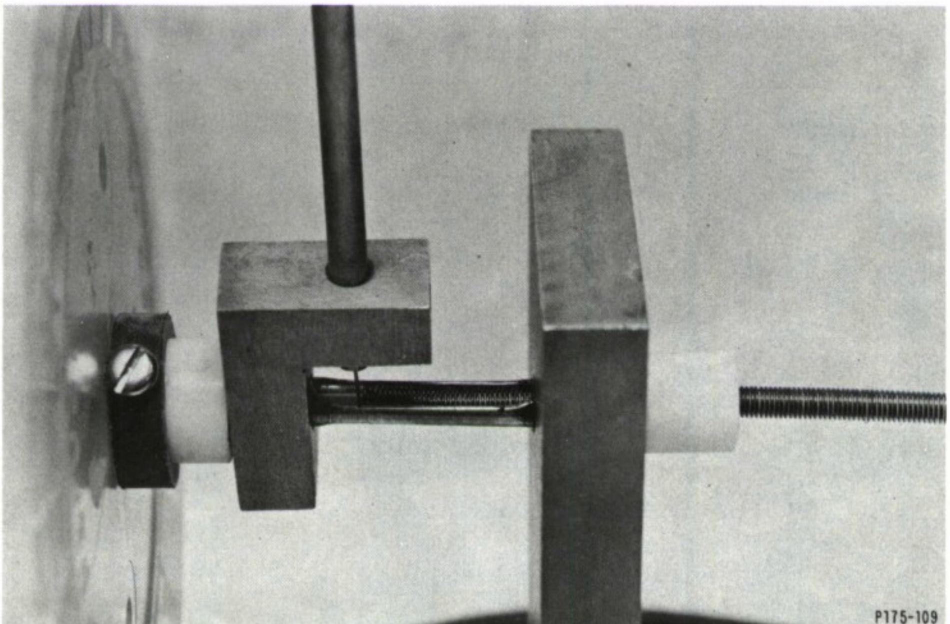


Fig. 17. Close-up of winding mechanism.

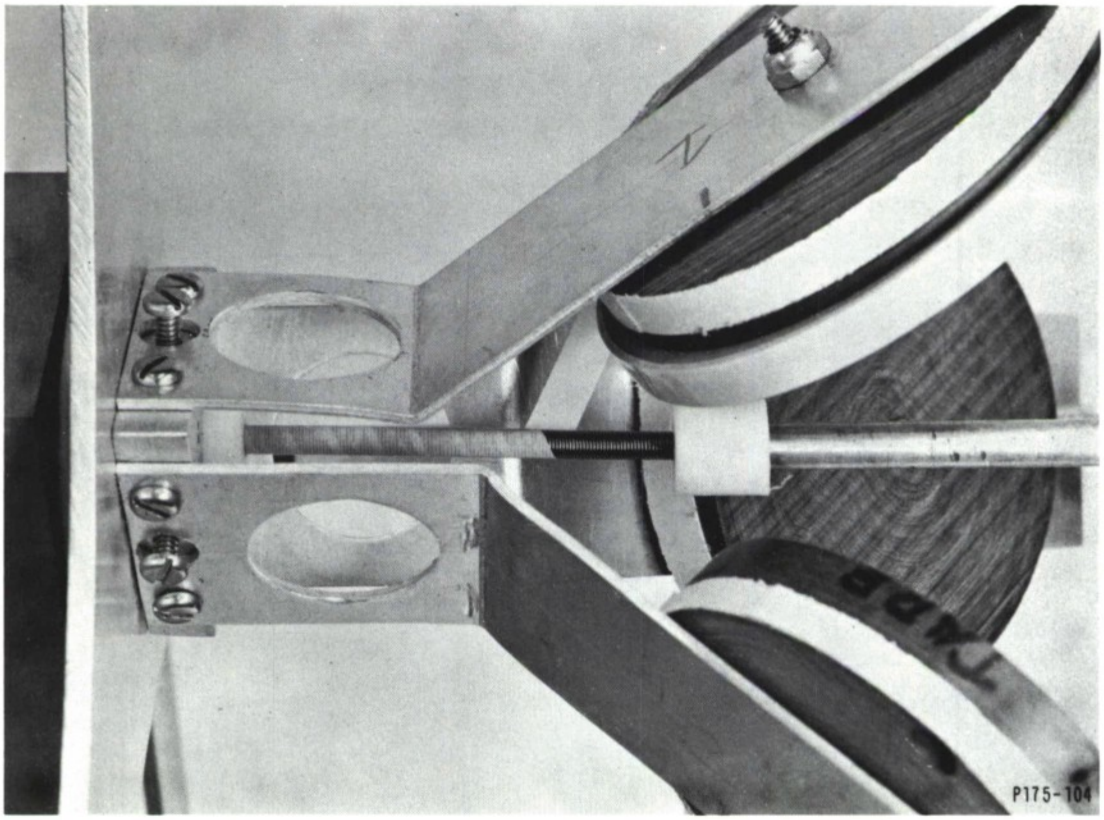


Fig. 18. Wrapping of single tape layer over coil.

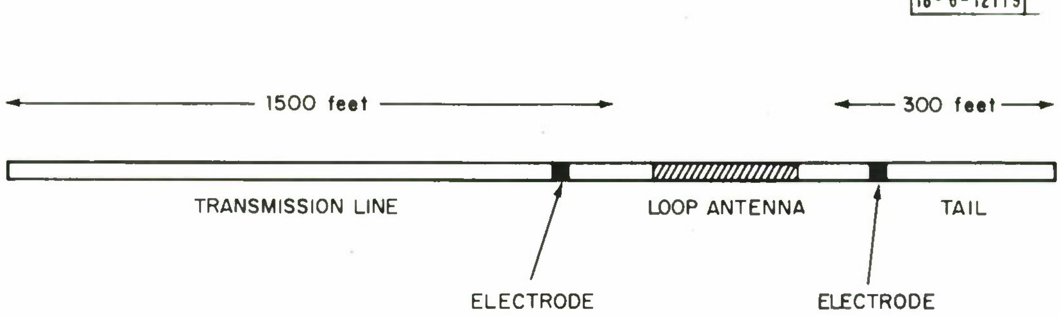


Fig. 19. Combined loop and electrode-pair antennas.

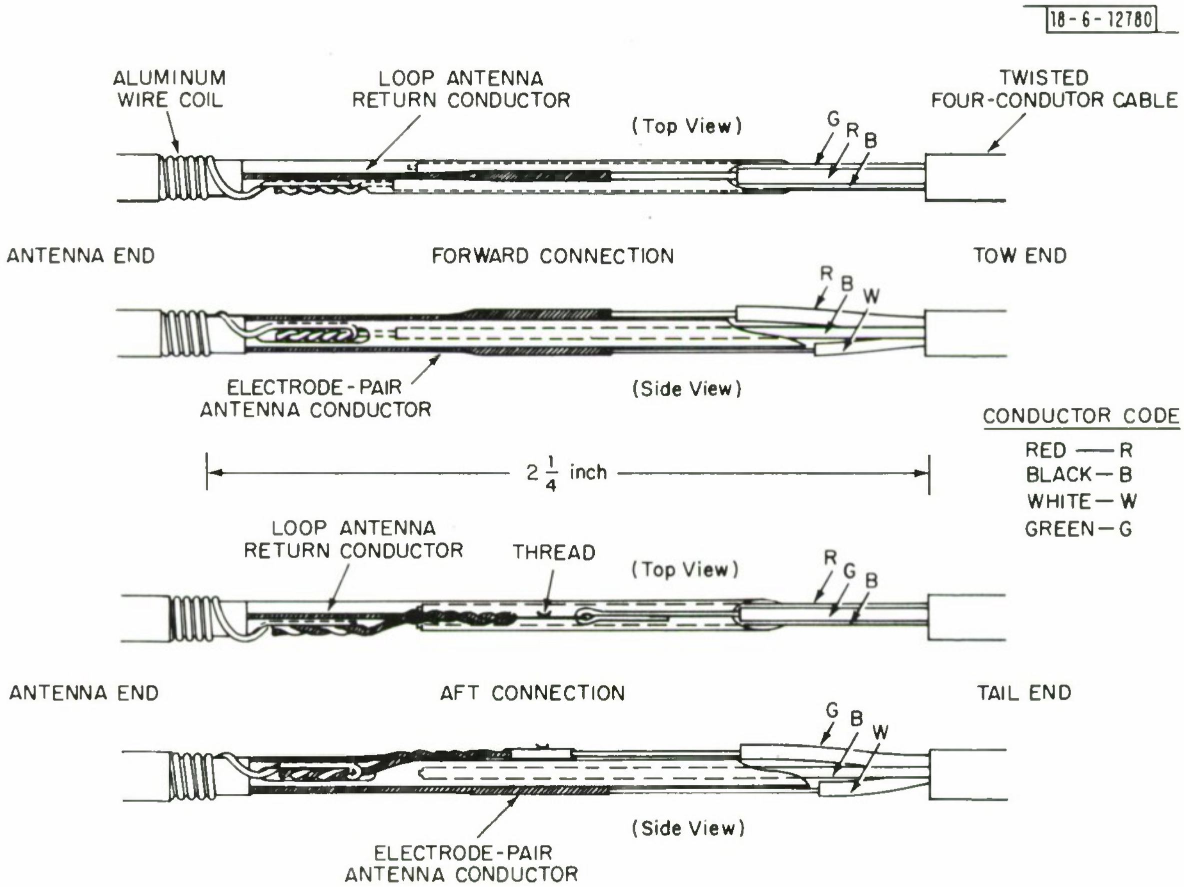


Fig. 20. Scale diagram of joints between antenna and four-conductor cable.

of each joint are presented.

For each joint, the bifurcated tube is cut obliquely, 1.75 inches beyond the end of the seal, the excess aluminum wire and binding tape removed and a 0.375 inch long hole cut in the wall of one chamber of the tube in the position shown. Then two of the conductors of the four conductor cable are pushed into the bifurcated tube, one in each chamber, and the connections made in the manner shown. The copper-to-copper connections are made using conventional 60-40 tin-lead solder; the aluminum-to-copper connections are made using the special solder and flux specified in the Material List (items 9 and 10). The fluxes are cleaned off with water, the joint dried and the whole is wrapped with polyester tape (item 4 of the Material List).

It is necessary to make a continuity check, when the hole has been cut at one end, to establish the side of the tube for the hole at the other end. Both holes should be in the position shown with respect to the electrode-pair conductor, which is the longitudinal conductor in the antenna connected at each joint to the white-coded conductor of the twisted four conductor cable.

To maintain the strength of the joint at the aft end, where only one electrical connection is made to the tail cable, a soldered loop is made in the green-coded conductor of the tail cable and in the return wire of the antenna. The two loops are mechanically connected as shown using four loops of cotton thread.

For the 50 ft. antenna the antenna section was joined to the four conductor cable with the coil end of the magnetic wire bundles towards the tail end of the cable. For the 100 ft. and 150 ft. antennas the coil end of the bundles is toward the tow end.

b. Molding and Taping

1. Apply RTV-511 primer to joint area and let dry for about 30 minutes.

2. Apply RTV-511 to joint area.

3. Place joint area in a split aluminum block with a

longitudinal hole 9/16" ID running along the split, and press tightly together.

4. After setting for 24 hours, open mold and fill any bubbles with RTV-102 and let air dry.

5. Tape joint area with hand wrapper, and continue wrap over transmission line for several inches.

14. Sheathing the Antenna and Four-Conductor Cable

Sheathing of the antenna provides the strength member for the cable, protection of the antenna assembly, a watertight jacket and buoyancy for the cable (Fig. 21). The inner-jacket ensures the watertight integrity of the antenna element if water penetrates along the fiberglass strand. It also strengthens the antenna assembly for the operation involved in laying down the fiberglass strands.

a. Inner-Jacket

The antenna and four-conductor cable assembly (core assembly) is taken to the sheathing company on production spools with a 12 inch diameter hub. The complete core assembly should be wiped down before taking it for sheathing. The inner-jacket (polyethylene) is tube extruded onto the core assembly at 40 ft./minute, and a gas jet flame is used to oxidize the polyethylene jacket on the four conductor cable to achieve a bond. The flame is removed as the antenna passes through. The OD of the inner-jacket varied between .200-.210 inches over the transmission line. Over the antenna there were sections where the inner-jacket ballooned slightly, however, the basic diameter was .200 ± .005 inches. Bunching of the polyester tape caused noticeable but negligible ripples in the jacket.

Our chief problem with the sheathing company was to convince them that their proposed set-up for the extrusion would bend the antenna excessively. The idler wheel feeding the tape-up reel was about 2" in radius. This wheel was therefore by-passed during the extrusion by a man hand feeding the cable onto the reel. Also, when re-spooling the cable, the cable

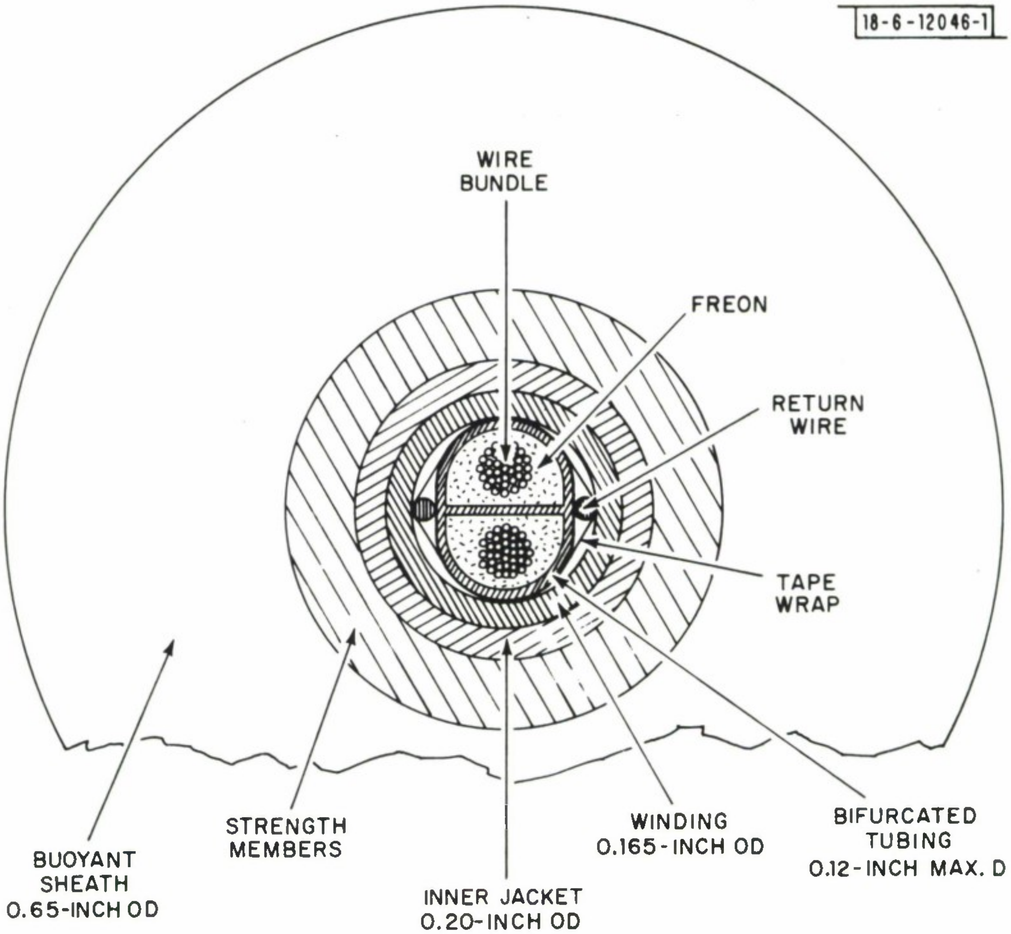


Fig. 21. Cross-section through antenna region of complete cable.

would have been excessively bent if the idler pulley had not been by-passed.

b. Fiberglass Strands

Eighteen strands of fiberglass were wrapped over the protective jacket using a 15 inch lay. Bending radius was again a problem, and the cable was hand fed onto the take-up reel. Also, a spool with a 2 ft. diameter hub was used for the take-up. A smaller hubbed spool was tried, but the fiberglass strands began to separate.

c. Foam Polyethylene Jacket

This jacket is extruded in two layers to minimize the internal heating of the cable. The first layer has a rough surface and the OD is .415-.425 inches. As the second layer is extruded, the first is again oxidized with a gas jet flame to bond the layers together. The OD of the second layer was $.650 \pm .005$ inches as measured by a diameter tape. The surface was very smooth. The first and second jackets were extruded at a rate of about 24 ft./min.

A tension regulating mechanism was used between the drive capstan and the take-up reel which bent the antennas through a diameter of 7 inches over an angle of 90°. This did not meet the bending radius requirement initially set in the specification, however, it was decided the effect would be negligible.

Density checks on the foamed polyethylene (.65-.70 specific gravity) were made before extrusion, and the density of the cable was measured after the extrusion. Under zero psi the specific gravity of a four-conductor cable section was 0.75, and it rose to 0.85 after one hour under 600 psi.

Temperature sensors placed on the surface of the bifurcated tube for the evaluation run indicated the internal temperature rise during extrusion was between $170^{\circ}F$ and $220^{\circ}F$. The temperature at the extrusion die is approximately $350^{\circ}F$.

15. Cable End Seal

A perfect watertight seal must be made at the tail end of the antenna cable to ensure that water does not hose down the inside of the cable and short the antenna. The following procedure is used to make an end seal (Fig. 22):

a. Cable Preparation

1. Cut back the cable and strip the conductors 1/8 inch. Bend back the conductors flush against the end of the cable and epoxy in place using the epoxy specified in item 17 of the Materials List. This ensures that the conductors will not short together during the molding operation.

2. Clean with isopropyl alcohol and dry thoroughly.

3. Mark cable 6-1/2 inches from end with tape.

4. Wrap tape around area held by clamps so as not to mar cable.

b. Heating Cycle

1. Clean blocks of mold and spray with Teflon mold release.

2. Turn on mold heater and maintain temperature of mold at $127^{o}C \pm 2^{o}C$ with a thermostat setting of 1-1/8.

3. Position fan to blow on guide tube only.

c. Molding

1. Insert 3.5 gms. of foam polyethylene pellets into mold.

2. Place cable into sliding block (Fig. 23) with tape 6-1/2" from end against aft end of block. Cable should be positioned into heating mold.

3. Place clamp block onto cable and fasten using two 1/4-20 cap screws 1" long.

4. Sliding block must be in retracted position.

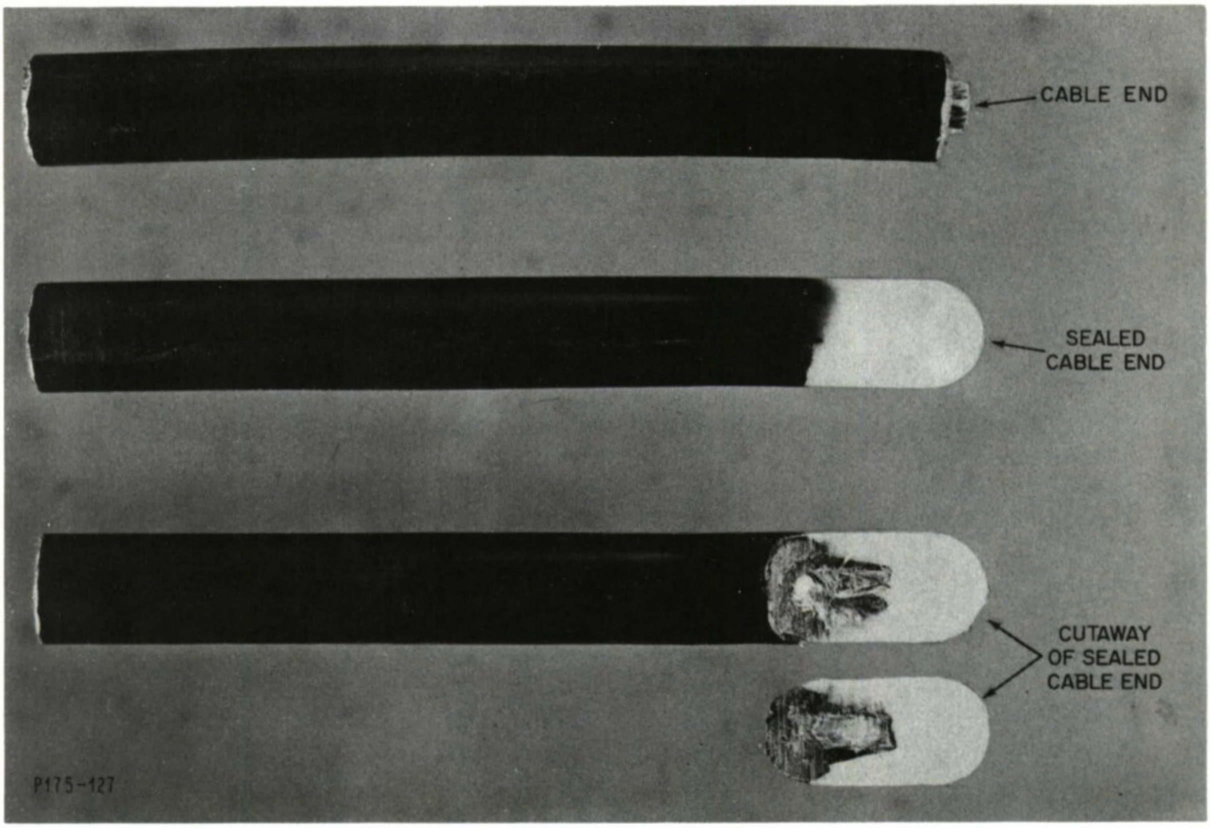


Fig. 22. End seal samples.

5. Set timer at 25 min.

6. When 5 min. remains on timer, slowly, with force, move sliding block forward into mold using 5/8" square gauge against aft stop. Allow 45-60 sec. for insertion. This permits trapped air to escape and also distributes the heat properly.

7. Hold at $125^{\circ}C$ for remaining 5 min.

8. Turn off heat.

9. Cool rapidly using a small fan to 50° to $80^{\circ}C$.

10. Clean off mold release and remove any small flash bits.

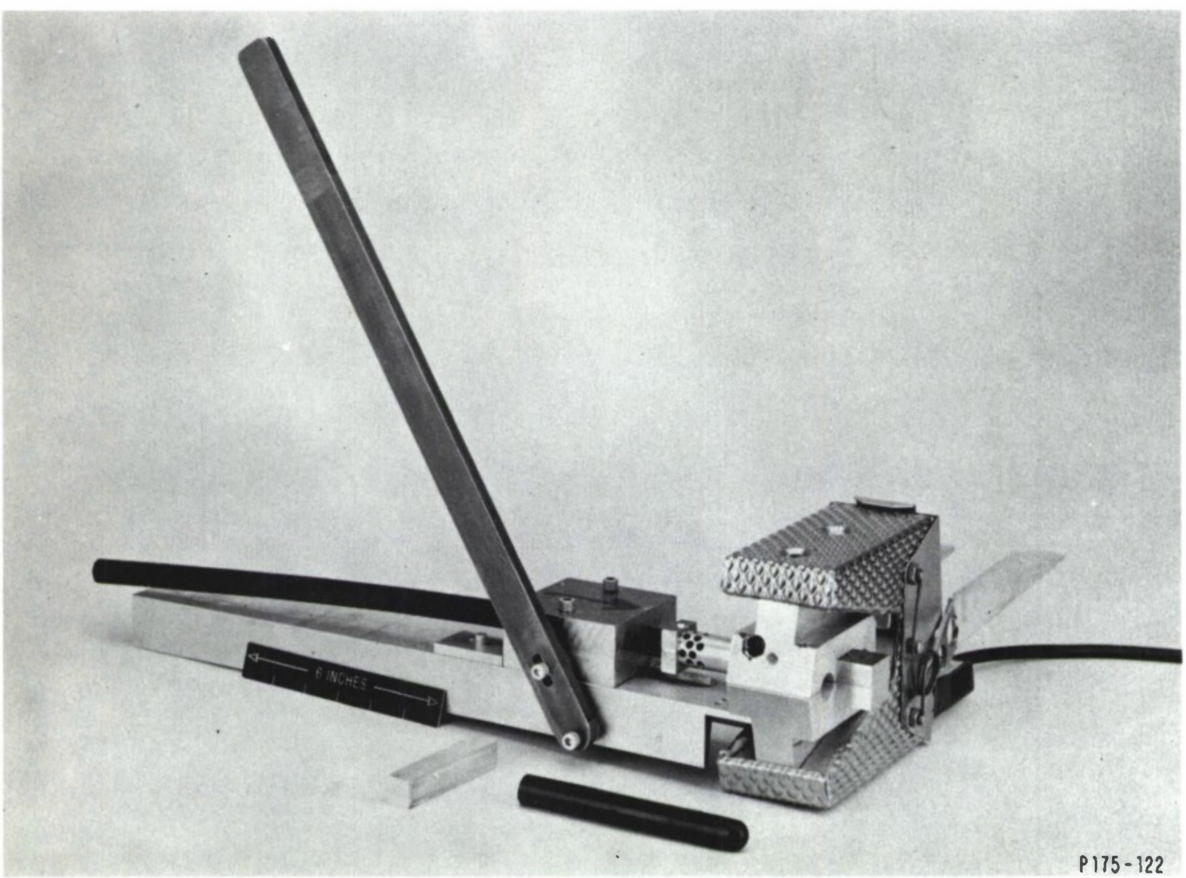


Fig. 23. End seal molding device.

APPENDIX

A. Material List

1. Bifurcated Plastic Tube - Made to Specification 1, Plastic Extrusion and Engineering Co., Inc., Westboro, Mass. (die is being retained by company.)

2. Magnetic Wire - Permalloy 80 wire, 0.005" dia., coated and permalloy annealed on mandrels in 40 strand bundle. Wire length on mandrels permits 2 ft. straight lengths to be cut from mandrel. Magnetics, Inc., Butler, Pa.

3. Stainless Steel Wires - Type 304 stainless steel wire, 0.010" dia., 3/4 hard, cut to 2 ft. straight lengths. Kenlen Wire Products, Co.

4. Polyester Tape - Tape No. 74, 1/4" by 72 yds., Scotch Brand, 3M Co.

5. Aluminum Wire - No. 26 aluminum wire, 10,000 ft. continuous length, triple layer of isomid insulation, REA Magnetic Wire Co.

6. Return Wire - No. 26 (7/34) stranded copper wire, tinned, no insulation.

7. Teflon Spacers - No. 24 thin walled Teflon tubing, Alphlex TFT-200, Alpha Wire Co.

8. Anti-Static Solution - Radio Shack anti-static record cleaning solution.

9. Soldering Flux - No. 37 Flux, All-State Welding Alloys Co., Inc.

10. Solder - Strongset, No. 509 solder, All-State Welding Alloys Co., Inc.

11. Nylon Thread - K46/2 Neophil, soft nylon thread, 4800 yds., Premier Thread Co.

12. Twisted Four Conductor Cable - Made to Specification 2, Mohawk Wire & Cable Corp.

13. Sheathing (Buoyant Cable Jacket) - Performed to Specification 3, Mohawk Wire & Cable Corp.

14. Freon - Freon E3 Fluorinated Ether, DuPont.

15. Polyurethane Resin - Humi-Seal, type 1A27, Columbia Technical Corp.

16. Plasticized P. V. C. Mixture - P. V. C. powdered resin type Diamond 74 mixed with dioctylphthalate plasticizer in the proportions 18 drops of plasticizer to 1 gram of resin. Diamond Shamrock Chemical Co.

17. End Seal Epoxy - Eccoband PDQ, Emerson and Cumming.

18. Crimp Epoxy - Type FS-90, Bipax 826/V140. Tra-Con, Medford, Mass.

B. Material Specifications

1. Bifurcated Tubing

a. Cross-Section Dimensions - As shown in Fig. 24 within a tolerance of ±.002 inch.

b. Material - Three types of rigid vinyl, each of different durometer.

c. Color - Clear or translucent.

d. Length - Two lengths of each material with a minimum continuous length of 1000 feet.

e. Die shall be retained for future extrusions.

2. Twisted Four-Conductor Cable

a. Conductors - No. 24 AWG solid copper wire with no joints or splices.

b. Conductor Insulation - Polyethylene extrusion to a diameter of 0.050 inches with each of the four insulations colored differently. A bond between each conductor and its insulation shall be established to prevent water hosing along the conductors.

c. Conductor Lay - The four insulated conductors twisted together with a lay of one inch.

d. Water Blocking Compound - To prevent hosing along outer

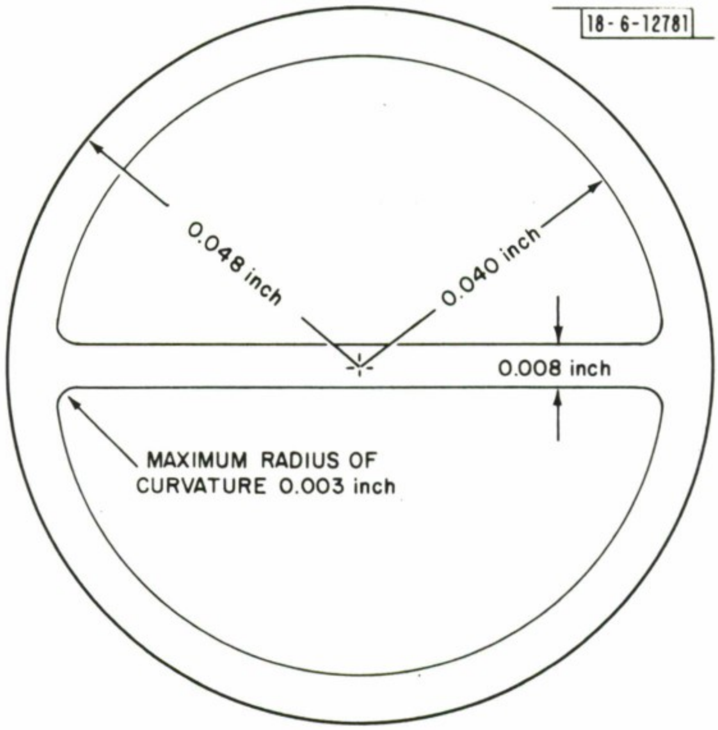


Fig. 24. Cross-sectional dimensions for bifurcated tube specification.

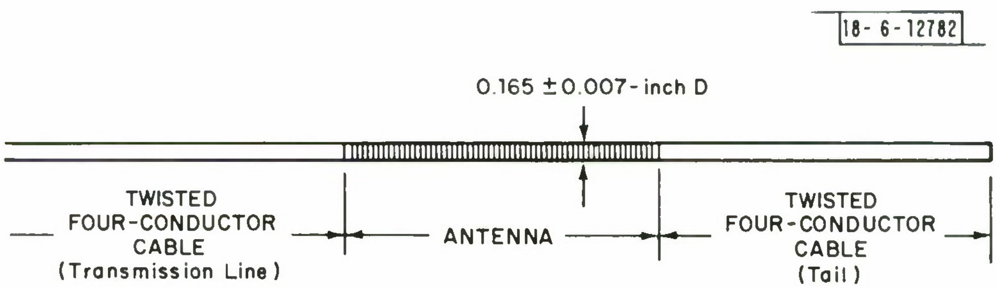


Fig. 25. Core assembly diagram for buoyant cable jacket specification.

surface of insulated conductors, water blocking compound (DPR, depolymerized rubber) applied between the twisted conductors.

e. Jacket - Polyethylene extrusion to jacket twisted insulated conductors together; final diameter of 0.165 ±0.005 inches.

f. Length - 10,000 feet total length in minimum of 2000 ft. with no joints or splices.

3. Buoyant Cable Jacket

a. Lincoln Laboratory prepared the core assembly consisting of the twisted four-conductor cable joined to the antenna (Fig. 25). The antenna consists of bundles of magnetic wires and a fluid in a rigid vinyl (P.V.C.) tubing which is then wound as a coil with insulated No. 26 aluminum wire for its full length. The core assembly has a diameter of 0.165 ±0.007 inches and the antenna section is approximately of circular cross-section. Excess bending of the antenna section permanently destroys the magnetic properties of the magnetic wire; therefore, at all times during fabrication the antenna section shall not be bent in less than a 10 inch diameter.

b. Inner-Jacket - Over core assembly, a continuous polyethylene extrusion (tubed) to a diameter of 0.200 ±0.005 inches.

1. For this extrusion every attempt shall be made to minimize the tension on the core assembly. The reel feeding the core assembly to the extruder shall be controlled or driven to reduce tension, and the number of pulleys/guides used for the extrusion should be kept to a minimum.

2. The minimum radius of curvature the core assembly shall be bent bent around is 5 inches (10 inch diameter).

3. During this extrusion, care should be taken to avoid excess heating of the antenna section of the core assembly. Deformation of the rigid vinyl tubing will defeat the antenna design.

4. A bond between this jacket and the underlying four-conductor cable jacket shall be established to prevent hosing between them.

c. Strength Members - At least 18 strands of 0.038 inch diameter fiberglass (ECG 75-5/3 Latex 2.0 "S" coated) laid on inner-jacket with a minimum lefthand lay of 20 inches. During this process, the minimum bending radius for the assembly shall be 5 inch (10 inch diameter), and tension on the assembly shall be kept to a minimum.

d. Buoyant Jacket - The jacket consists of two layers of a continuous, homogeneous, unicellular foam polyethylene. The extreme O. D. of the final cable shall be 0.650 ± 0.025 inches.

1. Minimum bending radius for this process shall be 5 inch (10 inch diameter).

e. Mechanical Characteristics - The cable jacket shall meet the standard requirements specified for this type of cable:

1. The outersurface shall be smooth, of uniform hardness, and free of imperfections.

2. The specific gravity shall not exceed 0.95 when measured under a hydrostatic pressure of 600 psig at room temperature in fresh water. An approved test method is contained in the Underwater Sound Laboratory Technical Memorandum 220-74-62.

3. Cold Bend - Cable shall pass cold bend requirements of MIL-C-17.

4. Crack Resistance - Cable jacket shall not crack when tightly wrapped around a 3 inch diameter mandrel for 24 hours.

5. Cable Strength - Minimum strength of cable shall be 2000 pounds. A reduction in jacket diameter to 0.580 inches constitues a failure during the test.

6. Shear Strength - Between strength members and jacket shall be a minimum of 100 pounds per linear foot of cable.

f. Measurement of Buoyant Jacket Diameter - Equipment shall be provided to continuously measure and record the diameter of the jacket over two diameters, 90° apart, and at a point in manufacturing where further dimensional changes will not occur. These recordings will be used by Lincoln Laboratory personnel to determine the overall success of the extrusion.

g. It is anticipated there will be at least two separate runs to produce a set of experimental cables.

1. Trial Run - Three separate core assemblies with short antenna sections (10 feet long) will be used to evaluate the fabrication process. Each core assembly will be 100 feet long.

2. "Production" Run - Three separate core assemblies with antenna sections between 50-150 feet. Each core assembly will be 2000 feet long.

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13. ABSTRACT

Three flexible loop antennas were fabricated for evaluation and testing as underwater, towed, ELF receiving antennas. This report presents a detailed description of the fabrication process and the materials used in the fabrication.

14. KEY WORDS

flexible loop antennas

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